Changes in Fecundity in a Stressed Population: Northern Cod (*Gadus morhua*) off Newfoundland

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Abstract

Recently determined relationships in stock fecundity off Newfoundland are compared with historical data from Newfoundland, Iceland, Norway, Baltic, and the North Sea and are used to establish baseline relationships between fecundity and size at age in Atlantic cod (*Gadus morhua*). A total of 200 prespawning female cod were sampled in 1999 and 2003 in three Northwest Atlantic management areas. For southern Newfoundland stocks that have fared relatively well in the 1990s and early 2000s, fecundity-size relationships did not differ from historical norms, although age at maturity was lower. In the highly stressed northern stock off Labrador, however, age at maturity was much lower than historical norms or in southern stocks, and fecundity much higher in small and young fish. Mortality rates were higher in the northern fish. We discuss these changes in the context of changed life histories and rebuilding in stressed gadoid stocks.

Introduction

Fecundity is a fundamental property of reproductive potential. Despite this importance, and the long history of Atlantic cod (*Gadus morhua*) fisheries in the North Atlantic, there have been relatively few fecundity studies on this species. The first studies were done by Earll (1880) and Fulton (1890), and later in the twentieth century by Powles (1958). In the northwest Atlantic, May (1967), Postolakii (1967), and Pinhorn (1984) provided estimates of fecundity for several stocks. More recently, many stocks off Newfoundland and Labrador have experienced exceptional

declines in biomass and remain at all time low levels (e.g., Lilly et al. 2000). Despite evidence of change in life history characteristics such as depressed age at maturity (Olsen et al 2004), growth (Dutil et al. 1999), and lower condition (Rose and O'Driscoll 2002) there has been no reassessment of historical fecundity information for these stocks.

In general, fecundity is the reproductive output of an individual, or number of offspring produced (Thain and Hickman 1994). There are three main types of fish fecundity described in Murua et al. (2003) and Kraus et al. (2000): *Relative fecundity* is the number of oocytes per unit body weight; *realized fecundity* is the total number of eggs spawned per season; and *potential fecundity* is the number of developing oocytes per female fish prior to spawning.

Our objective was to quantify the potential fecundity of Atlantic cod and its relationship with growth parameters in three major management areas. We then compare our results with historical data from the same stocks and from other cod stock areas across the North Atlantic.

Materials and methods

Study areas

Cod fecundity was investigated within three populations in NAFO (Northwest Atlantic Fisheries Organization), subdivisions 2J, 3KL and 3Ps (Fig. 1). Hawke Channel in subdivision 2J is located between Hamilton and Belle Isle Banks, and was the northernmost sampling site. Acoustic trawl surveys and fisheries research have been conducted in this area since 1994 (e.g., Anderson and Rose 2001). Samples from 3KL were taken from two areas; the offshore site, Bonavista Corridor, straddles the southeast limit of 3K and the northeast boundary of 3L. The Bonavista Corridor is the most southern migration route of northern cod and held the last large spawning aggregations in the early 1990s (Rose 1993). The inshore site, Smith Sound, Trinity Bay (Fig. 1A) is a fjord within subdivision 3L and currently holds the largest known concentration of overwintering northern cod, estimated at 26,000 tons in 2001. The cod that migrate along the Bonavista Corridor cross the 3K and 3L subdivision boundary lines, hence these areas were combined into 3KL for analysis. The third and final sampling area was Placentia Bay (Fig. 1B), which forms part of the inshore component of the subdivision 3Ps stock. Of all the cod stocks in the Northwest Atlantic, 3Ps rebounded the quickest after rapid decline in the late 1980s. This stock has had a small commercial fishery (average TAC of 15,000 t per year) since 1997. Placentia Bay cod have been under intensive study since 1996 (e.g., Lawson and Rose 2000, Mello and Rose 2005, Rose et al. 2008).

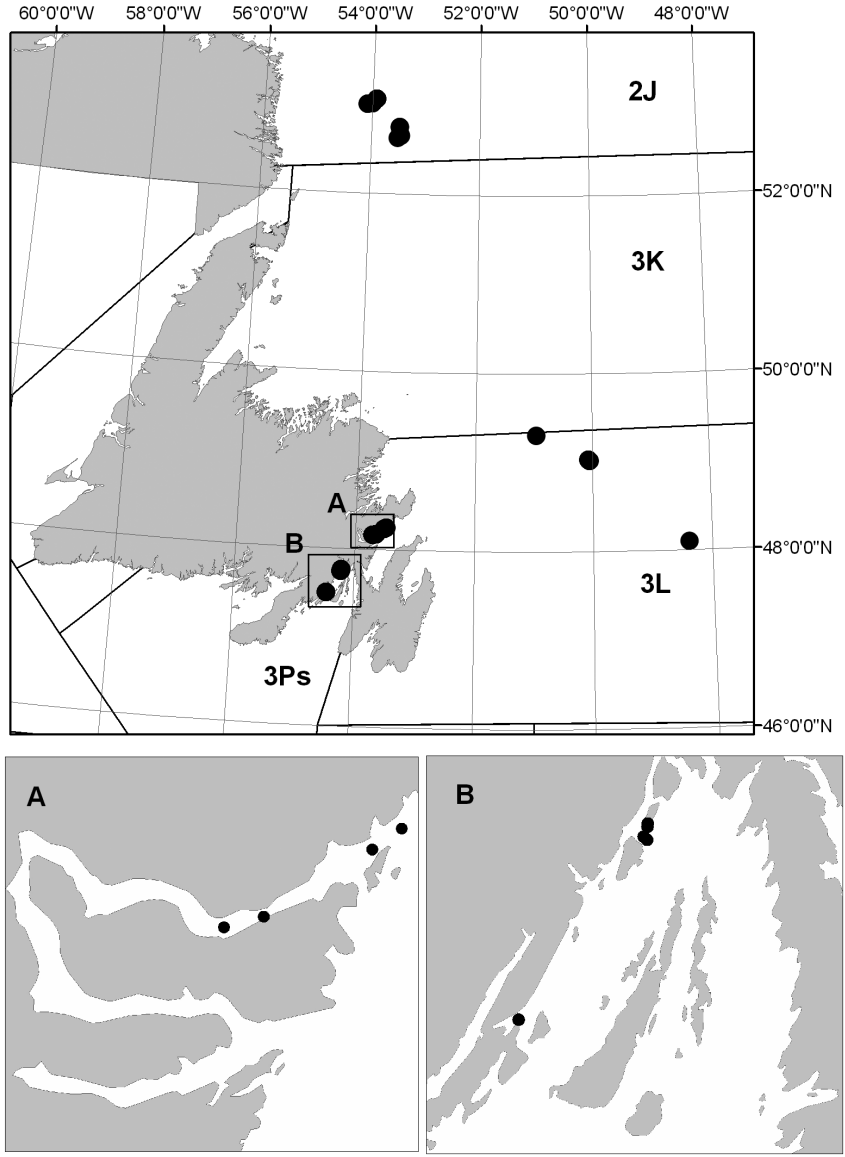

Figure 1. Sampling sites (●) and NAFO subdivisions for 1999 and 2003. Inserts represent coastal sampling sites Placentia Bay (A) and Smith Sound (B).

Table 1. Summary of female cod sampled during 1999 and 2003 within three NAFO subdivisions 2J, 3KL, and 3Ps. Information includes number of fish sampled, size (lengths and gutted weights), ranges, and standard deviations.

			Standard length (cm)		Gutted weight (kg)	
Area	Year	Sample size	Range	Average ± SD	Range	Average ± SD
	1999	31	40-60	48.6 ± 4.7	0.465-1.81	0.918 ± 0.270
2J	2003	12	42-61	49.3 ± 7.0	0.540-1.63	0.927 ± 0.396
	1999	27	35-82	62.0 ± 10.5	0.355-3.95	2.02 ± 0.962
3KL	2003	60	40-94	56.5 ± 12.0	0.472-6.60	1.53 ± 1.27
	1999	18	56-84	68.3 ± 9.3	1.21-4.61	2.57 ± 1.12
3Ps	2003	52	45-72	59.0 ± 5.2	0.653-2.61	1.61 ± 0.850
Total	–	200	–	–	–	–

Collections and preparation

Before spawning, a female cod gonad contains three sizes of eggs: large translucent eggs approximately 1.5 mm in diameter that are ready for release; middle-sized yolked eggs that will be released within weeks; and small whitish eggs (May 1967). The large and middle-sized eggs are first generation eggs and will be released in the current spawning season. The small whitish eggs are second-generation eggs, which will not be released until the following spawning year. Release of the large translucent eggs begins soon after oocytes become hydrated; therefore in order to measure fecundity gonads must be sampled before any hydrated eggs are visible (Raitt 1932). Female cod were sampled prior to and during the spawning seasons of 1999 and 2003. In 2J and 3KL, fish were sampled with a research otter trawl (Campelen 1800), whereas samples were caught using handlines in 3Ps.

Standard lengths, and whole, gutted, liver and gonad weights were recorded, with otoliths taken for aging. Fish sizes varied between areas (Table 1). In all analyses, gutted weight was used as opposed to whole weight to reduce bias resulting from seasonal changes and variations due to feeding. Extracted ovaries were cut down the middle and placed in a labeled jar, and Gilson's fluid (Simpson 1951) was then added to cover the ovary, to aid in the breakdown of connective tissues and the separation of eggs from each other and the ovarian wall. Samples were topped up with fluid and agitated once a week to help speed the breakdown process, and then were left for an average of three months before processing. When separation was complete, each sample was passed through a series of interlocking sieves of differing mesh sizes (1.4 m, 1.0 m, 500 m, 300 m, 180 m, 125 m). Remnant ovarian wall tissue and

second-generation eggs were discarded, and eggs were stored in jars with 90% ethanol until processed.

Subsampling and counting

Most methods used to measure fecundity involve taking a subsample of the total volume of eggs in an ovary. The Motoda splitter (Motoda 1959) is primarily used for plankton subsampling, but has been used in fecundity studies (Allain 1999) and was used in the present study. The splitter produces subsamples by successive fractionations. Counts were done manually using a stereomicroscope and handheld counter; two subsamples from each gonad were counted three times. All samples met the required <5% variation. The combined total 6 counts were averaged and used in the estimation for the total number of eggs in that sampled ovary. The potential fecundity per fish was determined by the following equation:

$$N_{eggs} = N_{eggs\ in\ subsample} \times \text{Subsample split fraction}$$

For comparison, six egg samples of random sizes were subsampled a second time using the whirling vessel. Average difference of potential fecundity estimates between the Motoda splitter and the whirling vessel was 10%. Using a paired *t*-test, no significant difference was found in the determined fecundities between the two methods ($p > 0.05$, $\alpha = 0.05$).

Fecundity analyses

Initially all data were pooled and a series of regressions were performed to determine the presence or absence of general relationships between fecundity and specific measured growth variables. Fecundity was investigated in relation to fish length, age, gutted weight, and liver and gonad indices. Liver index (LI) and gonad index (GI) are defined as:

$$\text{LI} = \text{Liver weight/Total weight} \quad (2)$$

$$\text{GI} = \text{Gonad weight/Total weight} \quad (3)$$

Fecundity was also investigated in relation to condition (Fulton's *K*). Fulton's condition examines the relation between length and weight and is used to quantify the state of well-being of a fish (Wooton 1990a), and is measured as:

$$K = \text{Total weight (kg)/length}^3\ \text{(cm)} \quad (4)$$

Significant relations were further explored through a series of 3-factor ANCOVAs, after which the data were categorized by study area. Results include samples from 1999 and 2003 except for the offshore area of Bonavista Corridor within 3KL (Fig. 1). Data were transformed into base

Table 2. Comparison of original fecundity-weight relations in cod of different geographic regions of the North Atlantic.

Population/ area	Original function	Weight units	n	Source
NAFO 2J	F = 2.09W + 6.04a	kg	43	This study
2J-3K	F = 0.48W + 0.01a	kg	8	May 1967
Labrador	F = 0.2118W + 0.041b	g	65	Postolakii 1967
	F = 569W – 80,7000	g	92	Oosthuizen and Daan 1974
North sea	F = 526W – 548,000	g	47	Schopka 1971
	F = 790W – 41,600	g	49	Botros 1962
Norway	F = 0.334W1.126	kg	240	Kjesbu et al. 1998 (weighted average)
	F = 633W + 88,791	g	807	Kraus et al. 2000 (weighted average)
	F = 860W – 297,000	g	71	Botros 1962
Baltic	F = 746W + 95,000	g	84	Schopka 1971
	F = 519W	g	42	Joakimsson 1969
Iceland	F = 584W – 832,000	g	49	Schopka 1971

[a]Log-log regression.
[b]Fecundity in thousands of eggs.

10 logarithms to standardize variance and facilitate historical comparisons (e.g., Pinhorn 1984).

A comparison of linear regressions of fecundity-weight relations of cod from different geographic regions of the North Atlantic was also performed. Available data and original equations were gathered from 11 published studies, representing Labrador, North Sea, Norway, Baltic, and Iceland (Table 2).

Results

The overall range of lengths, weights, and ages of cod sampled was 40-94 cm, 0.355-4.61 kg, and 4-14 years, respectively (Table 1, Fig. 2). On average, mature female cod sampled from 2J were of lesser length, weight, and age than those at the other sites in both sampled years (Table 1); mature 2J cod were all less than 7 years of age (Fig. 3).

Regression analyses indicated the strongest predictors of fecundity were weight, length, and age respectively (Table 3). The regressions of fecundity on these variables were significant in all regions, with the amount of explained variation ranging from 31 to 72%. Fecundity was also associated with Fulton's K in all regions ($p < 0.05$). No overall association was evident between fecundity and liver (LI) or gonad index (GI); however, fecundity was significantly correlated with liver index in 2J, and to gonad index in 3Ps. Month was factored into a GLM model to

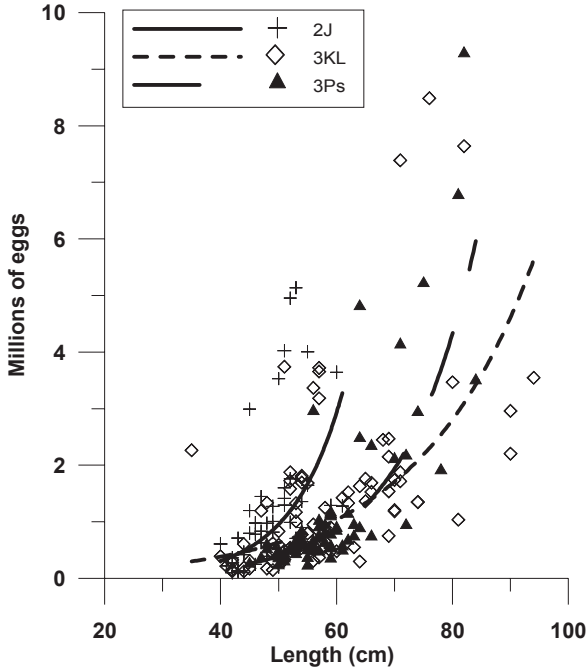

Figure 2. Scatter diagram of fecundity against length for the three NAFO areas sampled; 2J, 3KL, and 3Ps.

control for seasonality. It was found that the relation of fecundity to gonad index did not change across months sampled in 2J, 3KL, or 3Ps.

Fecundities differed significantly between the two years of sampling (1999 and 2003) by a factor of 2-4. In a 3-way ANOVA using year, region and gutted weight as factors, year and region were significant effects but did not interact ($p = 0.08$). Hence for all subsequent analyses data were pooled by year.

Analysis of covariance indicated that the slopes of the regression lines of fecundity on length, age, and weight differed significantly between 2J, 3KL, and 3Ps ($p's < 0.01$). Among the years the relationships were strongest in 3Ps cod (Table 3). Cod in 2J had much higher fecundities at small sizes and younger ages than did cod from other regions. In 2J and adjacent 3KL, fecundities differed greatly from those reported by May (1967) and Postolakii (1968). At age 5 cod had fecundities similar to those at age 12 historically (Fig. 5), and with cod six times their size (Fig. 6).

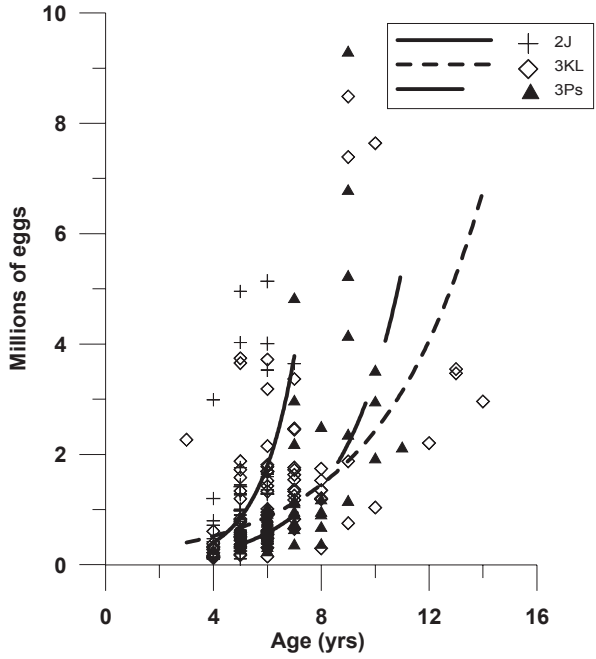

Figure 3. Scatter diagram of fecundity against age for the three NAFO areas sampled; 2J, 3KL, and 3Ps.

Additional fecundity and weight data for six North Atlantic cod populations were examined (Labrador area, NAFO subdivisions 2J-3K, Baltic (east and west), North Sea, Iceland, and Norway (Barents Sea) (Table 2, Fig 7). Where more than a single fecundity relationship was available for an area (except Norway), weighted averages were used to produce a representative regression. Due to large variance between the samples from Norway, these data sets are separated, but both indicate some of the highest weights and fecundities overall. Historical data from 863 female cod from 2J-3K (Postolakii 1967 and May 1967) have the lowest fecundities (and smallest weights) of all the stocks examined, but in the present study cod from this area had much higher fecundities at the same weights.

Discussion and conclusions

Results of the present study indicate that potential fecundity of Atlantic cod is strongly correlated with weight, length, and age and less so with somatic and liver condition. A relationship between gamete production